



Petroleum Accumulation Conditions in Liaodongdong Exploration Area of Shengli Oilfield

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Abstract: Based on the theory of petroleum geology, the author systematically analyzed the oil and gas accumulation conditions of Liaodongdong exploration area of Shengli oilfield. Application of effective hydrocarbon source rock analysis, reservoir prediction and evaluation, basin analysis, basin simulation technology and method of hydrocarbon accumulation model is established. The research results show that Liaodongdong exploration area develops many sets of source rocks which buried depth below 2500 m. Hydrocarbon source rocks with high abundance of organic matter and excellent conditions for mineralization. This area develops Guanxia group and Dongying group of two sets of effective reservoir-cap combination, and develops variety of drainage system and various trap types. Different structural belt have different drainage system and trap types, formation of multiple trap types. Liaodongdong exploration area of Shengli oilfield mainly formed four types of reservoirs, which include lithologic-structural reservoir, stratigraphic overlap reservoir, stratigraphic erosion unconformity reservoirs, lithologic reservoirs.

Keywords: Eastern Liaodong exploration region of Shengli Oilfield, Hydrocarbon source rocks, Trap types, Carrier systems, Types of patterns of reservoirs

1. Introduction

Bohai Sea waters is an upper Mesozoic and Cenozoic era superimposed petroliferous basin on the basement of Mesozoic group, which is also a part of Bohai Bay Basin[1-5]. Eastern Liaodong exploration region of Shengli Oilfield is located in the eastern Bohai Bay (120°35'~121°50'E, 38°30'~40°10'N; see Fig. 1). The region is a Shallow-Sea area located nearby Liaodong sag, Bodong sag and Miaoxi sag.

The degree of prospecting before is pretty low in this area, there are only some results of the 1: 200, 000 gravimetric reconnaissance and geomagnetic survey before 2003. In 2003, 2004, 2005, 2D seismic acquisition, 3D seismic exploration and drilling engineering were applied in southern exploration region of Shengli Oilfield. Until now 7 exploratory wells have been completed and the oil-gas layer has been discovered in 3 of them. This shows the potential of oil and gas contents in this area[6-7].

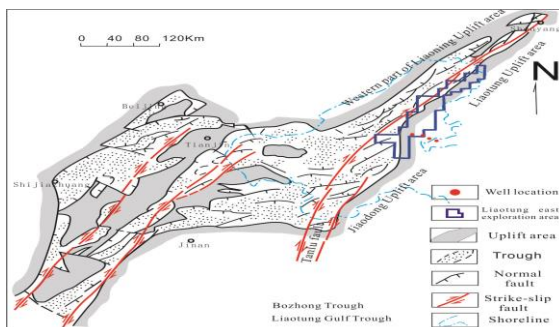


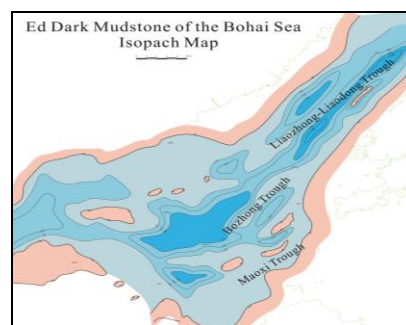
Figure 1: Simplified geological map of Eastern Liaodong explosion region, Bohaiwan Basin

This paper focus on the analysis of basin, effective studying of hydrocarbon source rock, the prediction and assessment of reservoir stratum and the analysis of basin modeling order to conduct a comprehensive research on the hydrocarbon accumulation condition and summarize the hydrocarbon resource potential in the research area.

2. Oil Source Condition

The study region is next to Liaodong sag, Bodong sag, Bozhong sag, and Miaoxi sag. The hydrocarbon source rock here has some characteristics of multiple reservoir layers, large thickness, and wide distribution.

Besides some Paleogene layers like the Kongdian Formation, Shahejie Formation of land area, there are mature hydrocarbon source rocks in Dongying Formation. The Kongdian Formation and Shahejie Formation are the most important source layers, with abundant organic matters and buried in more than 2.5 km depth (see Fig. 2; Table 1).



(a)

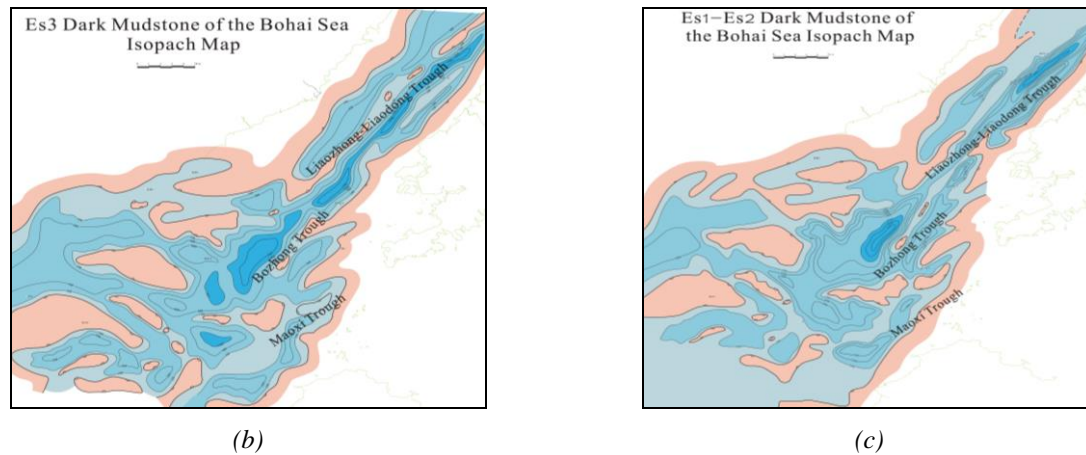


Figure 2: (a, b, c) Isopach map of hydrocarbon source rocks in Eastern Liaodong exploration region

Table 1: Amount of organic matters and evaluation of different hydrocarbon source rocks from Eastern Liaodong exploration region

Depression	Horizon	TOC(%)	S1+S2(mg/g)	HC(mg/kg)	Organic matter type	Evaluation
Bozhong and Bodong	Ed	0.42-4.87	0.72-32.28	3042-6009	II 1	Excellent
	Es1	0.67-8.74	1.78-67.47	3058-7466	I - II 1	Excellent
	Es3	0.72-4.81	2.54-33.74	100-12526	II 1	Excellent
Liaoxi	Ed	1.3-1.5	3.55-5.31	198-498	II 1	Average
	Es1	1.76-2.08	6.65-14.98	1001-1004	II 1	Good
	Es3	1.04-1.77	3.33-6.59	672-906	II	Average
Liaozhong	Ed	1.36-2.17	4.71-11.03	342-4130	II 1	Good
	Es1	1.62-2.52	10.72-14.09	1187-2556	I - II 1	Good
	Es3	1.19-1.66	3.16-6.83	853-1610	II 1	Good
Miaoxi	Ed	2.5	16	6009	II 1	Excellent
	Es1	1.73	5.83	3738	II 1	Good

3. Reservoir Conditions

3.1 Reservoir Rocks

The oil reservoirs in study area mainly are middle-upper Proterozoic reservoir, Tertiary sandstone and the fourth group of Shahe Formation-Kongdian volcanics from the bottom up.

In middle-upper Proterozoic reservoir, there are mainly phanocrystalline- aphanitic limestone, marlite and argillaceous limestone, which are presumed to be the epicontinental sea sedimentary environment by using the data of the adjoining area. These rock reservoirs are basal sedimentary rocks, having the shape of being thin in the middle and thick in circumference, especially have a large thickness in downthrown side of the strike-slip fault.

The Tertiary sandstone is broadly forming in Shahejie Formation, Dongying Formation, Guantao Formation and Minghuazheng Formation. The reservoirs of Dongying, Guantao and Minghuazheng formation have typical regional distribution characteristics. The reservoir sand bodies of Dongying are the one of subaqueous distributary channel bodies and mouth bar in delta facies. In the lower segment Guantao

Formation the reservoir is meandering river sand body with high content of mudstone; the reservoir in Minghuazheng Formation is braided river bar body.

In 4rd member of Shahejie Formation-Kongdian Formation, reservoirs are made up of andesite and volcanoclastic rocks, which are speculated widely developed in tancheng-lujiang fault zone.

3.2 Reservoir Physical Property

Only In Shengshun well 8, the existence of the carbonate reservoir of Middle-Upper Proterozoic has been confirmed. According to the logging information of Shengshun well 8, the porosity and permeability of this reservoir were 3.998%~13.74% with average of 11.3% and $0.1 \times 10^{-3} \mu\text{m}^2 \sim 4.27 \times 10^{-3} \mu\text{m}^2$ with average of $3.5 \times 10^{-3} \mu\text{m}^2$. With water producing 129 t/d in the well section at 883.71m-988.00m, this reservoir physical property is good.

In the Tertiary sandstone, porosity of reservoir stratum in the Dongying Formation is 15~26% in general, weighted average thickness is 25%, and permeability is $0.1 \sim 145 \times 10^{-3} \mu\text{m}^2$ with average of $28 \times 10^{-3} \mu\text{m}^2$. This section is mainly about a middle pore and low permeability reservoir. Porosity of

reservoir stratum in the lower segment Guantao Formation is 14~34% in general with average of 25%, and permeability is $0.1\sim 145\times 10^{-3}\mu\text{m}^2$ with average of $28\times 10^{-3}\mu\text{m}^2$. This section is a high pore and middle permeability reservoir.

In 4rd member of Shahejie Formation-Kongdian Formation, the reservoir space is mainly of fracture and solution pore. In the core sample from well section 1338m, there are about 80 pores, the maximum pore size is 10mm×25mm but 1mm×3mm in general. Most of the pores have been corrode and about 5% of these pores have been packed with calcite, others with crude oil (see Fig. 3). There are 15 near-vertical dip angle and high angle fractures in the core, all the fractures have good fracture apertures. There is crystallization calcite on the surface of fracture, which has mostly filled with black viscous crude oil (see Fig. 4). The solution pores were almost connected by dissolution fissures and micro fissures, these show a definite reservoir property.



Figure 3: Solution pores in basalts of Kongdian Formations in Shengshun 100 exploratory well



Figure 4: Heavy oil in the solution pores of Kongdian Formations in Shengshun 100 exploratory well.

3.3 Comprehensive Reservoir Evaluation

From Table 2,3, the percent content of Dongying formation sandstone in study area is decreased gradually from west to east and south to north. The ratio of reservoir between strata is 40.5% in Shengshun well 100 with lower position, 27.1% in Shengshun well 2 with higher position and 33.3% in Shengshun well 1 of Dongying formation. All the reservoirs are mainly type I, III and can be considered as good oil-bearing layers. The percent content of lower Guantao formation sandstone is increased gradually from west to east. The ratio of reservoir between strata is 37.6% in Shengshun well 100 with lower position, 50.8% in Shengshun well 2 with higher position and 40% in Shengshun well 1 of Dongying formation. All the reservoirs here are mainly type I, III and can also be considered as good oil-bearing layers. Both formations are most important oil reservoir positions.

Table 2: Statistics of formation thickness, reservoir thickness, and ratios of reservoir thickness and formation thickness

Horizon	Upper Guan member			Lower Guan member			Dongying Formation			Sha NO.1		
	total thickness (m)	Sandstickness (m)	Storage/Ground (%)	total thickness (m)	sand thickness(m)	Storage/Ground (%)	total thickness (m)	Sands thickness (m)	Storage/Ground (%)	total thickness (m)	Sands thickness (m)	Storage/Ground (%)
Shengshun 100	230	186.3	79.6	271	102	37.6	152	61.6	40.53			
Shengshun 1	208	128	61.7	260	104	40.0	108	36	33.3			
Shengshun 2	199	98	49.3	248	126	50.8	98	26.6	27.1			
Shengshun 4	221.5	183.5	82.8	298.5	113	37.9	171	50.5	29.5			
Shengshun 5	270	202.5	75	269.5	108	40.3	230	80.5	35	41.5	15.5	37.3
Shengshun 6	136	93	68.4									
Shengshun 8	189.5	147.5	77.8	67.5	26	38.5	49	16	33			

Table 3: Reservoir's Evaluation in the Eastern Liaodong Exploration Region

Horizon	Porosity /%	Average /%	Permeability /10-3μm2	Average /10-3μm2	Sedimentary environment	Reservoir type	Comprehensive evaluation
Upper-middle Proterozoic carbonate rock	3.998~13.74	11.3	0.1~4.27	3.5	Marine	II	Good

Dongying Formation	15~26	25	0.1~145	28	Braided river and meandering river	I,III	Good
Minghuazheng Formation	23.4~37.5	32.6	568.2~4459.8	2605.3	Braided river	I	Poor
The 4th member of Shahejie Formation and Dongdian Formation	—	—	—	—	Coastal shallow lake facies	III	Average

4. Cap Rock Condition and Reservoir-seal Assemblage

Except the sandstone in the lower segment Guantao Formation, there is also one mudstone layer with thickness of 20-60m. The reservoir-seal assemblage consisting of this mudstone and sandstone here is one of the best reservoir-seal assemblages in Bohai Sea, even in the Eastern Liaodong exploration region. In this assemblage, multiple instances of large stratigraphic oil-gas reservoirs have been found.

In top Dongying Formation, there is also one mudstone layer with thickness of 30-90m that can be considered as a good cap rock. The reservoir-seal assemblage consisting of this mudstone and the delta sandbody here is also one of the best reservoir-seal assemblages in the study area. All the drill holes data have encountered the hydrocarbon zones.

In addition, there are multiple partially reservoir-seal assemblage, such as Pre-tertiary to tertiary Formation reservoir-seal assemblage and the 4rd member of Shahejie Formation-Kongdian Formation reservoir-seal assemblage. The drill hole of Shengshun well 2in Minghuazheng reservoir-seal assemblage has found gas reservoir and the Shengshun wells 1 and 2 in Shahejie Formation-Kongdian Formation reservoir-seal assemblage have found oil reservoir. In general, these assemblages distribution is relatively limited in exploration region.

5. Passage System

Hydrocarbon passage systems are used to be composed of fractures, planes of unconformity and sand bodies. All the factors exist in exploration region, different passage systems in each tectonic zone and position constitute one multiple transport system.

5.1 Sandstone Passage System

Sand body could either be the hydrocarbon reservoir space, or the migration pathway. It is the most basic passage system. It is indicated that this kind of transported system in the study area has some useful factors such as the distribution in the plane, the thickness, sand-mud ratio, porosity and permeability of sand bodies, that has well-controlled effect on the hydrocarbon migration and accumulation.

The formation thickness in Shahejie and Kongdian is relatively small to the erosion thickness at the top.

The distribution of this formation is quite limited that it is only been partly discovered in Shengshun well 5, to forming the regionality passage system.

The Dongying Formation here is semi-deep lake-lakeshore-shallow lake- deltaic deposit, which can be mainly subdivided into the delta plain and the delta front facies. These sandstones are characterized by a small range of extension and distributed along river's main channel. But if viewed as a whole, sand-mud ratio in this Formation is low. From west to, east, the ratio varies from 15% to 11%, 24%, 22%, 17% in Shengshun wells 5, 4, 100, 1, 2, 8, 6, that shows a tendency of the ratio from low to high then turned to low again. Only in Shengshun well 1and100 the sand accounts for more of the total. So the Dongying Formation cannot form the regionality passage system as well.

There are thick-massive braided river bar bodys in both lower Minghuazheng and top Guantao Formations. The thickness of a single layer is 15-20m in general and sand-mud ratio is above 70%. The Dongying Formation can form the regionality passage system with the good sand connectivity (rate of overlay 75%).

5.2 Fault Transportation System

In both "lower- source and upper reservoir" and "new source to old reservoir" systems of the source-reservoir-cap allocation system, the key of hydrocarbon accumulation is the passage system. In this area, chronic activity basement fault is still strongly active in the Tertiary Sedimentary, some active traces even can be found in the Minghuazheng Formation. It is the important time in the phases of hydrocarbon expulsion to from source rocks. These faults not only controlled the range of the oil-gas source depression in downthrown side, but also connected with some traps as buried hill drape structures in the upthrow side, this made the faults into the main oil source fault between the traps and oil sources. At the same time, because of the neotectonics movement, many superficial faults formed in the superficial layer of the Tertiary Fomation. Those late faults and early basement fractures composed the vertical pathways systems for oil-gas transportation. The length of oil-gas bearing intervals in Shengshun well 1 Dongying formation and lower Guantao formation is 454m (975-1429.2m), and high commercial production rate of oil flow tested here is

80.3 t, 75.5 t each section. All of these proved the network of faults is the mainly transportation system.

5.3 Unconformity Transportation System

There are multi-period regional planes of unconformity here, such as: the plane between the Tertiary and Pre-Tertiary, between the 4th Shahejie – Kongdian group and Dongying Formation, between the Dongying and Guantao Formation. Those planes of unconformity with wide extension, large area and long sedimentary interruption period, can form the main channels for vertical hydrocarbon migration after cut by faults.

The porosity of the area can reach 7.05% in Shengshun well 1, the upper of the 4th Shahejie – Kongdian group, and permeability is about $0.963 \times 10^{-3} \mu\text{m}^2$. The 4m shows oil flecked in 4 layers in logging. The porosity of the area can reach 6.4% in Shengshun well 100, the upper of the 4th Shahejie – Kongdian group, and permeability is about $1.02 \times 10^{-3} \mu\text{m}^2$. The 36.0m shows oil flecked in 3 layers in logging. The result emphasized the unconformity is taken as the paths of lateral oil and gas migration. Test of Shengshun well 81 show about $46\text{m}^3/\text{d}$ water in the Upper Neo-proterozoic. The basement rock unconformity is the main pathway system (see Fig. 5).

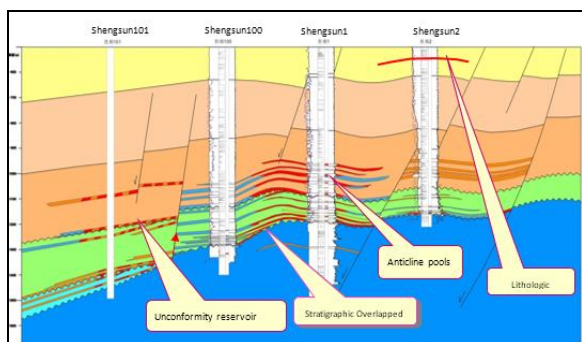


Figure 5: Oil reservoir section with east west direction in Eastern Liaodong exploration region

Based on the structural styles in Eastern Liaodong exploration region, there are depression belt in west, strike-slip fault tectonic belt in the middle and stratigraphic overlap tectonic belt in east. As different structural styles in different tectonic belt have different communications with source rocks, the transportation systems in each belt have different features.

In west depression belt, the Shahejie, Dongying Formation of downthrown side of the faulted slope fold belt connected with the source rocks directly, the oil-gas do not need to be transported for long distance and can be accumulated in the traps immediately. For those traps in the Neogene, the oil-gas can be vertical migrated through the basement fractures. So, the transportation system here is the simplest one.

There are fault nose and fault block tectonics of Dongying Formation and the Neogene in the middle

strike-slip fault tectonic belt. There are also some stratigraphic traps in the Middle monoclinical structural zone. Those traps are made by stratigraphic overlap of Dongying Formation or 4th Shahejie Group and Kongdian Group, the reservoir forming here needs multiple passages. Comparing with the Jiyang rag, the mainly transportation system here could be the meshwork-carpet type. The oil-gas vertical migrated through the basement fractures, and then turned into lateral migration through the carpet reservoirs of Dongying delta sand body or Neogene fluvial facies. With the superposition of late stage faults, the three-dimensional transportation system finally formed. As the stratigraphic overlap belt has some distances with the reservoir rocks, there may be multilayer transportation system. The unconformity plain and the meshwork-carpet reservoir of Neogene should be the significant transportation system here.

6. Trap Condition

Based on the structural styles in Eastern Liaodong exploration region there are depression belt in west, strike-slip fault tectonic belt in the middle and stratigraphic overlap tectonic belt in east. Different trap types and trapping assemblages in different tectonic belt, that formed the complex trap zone (see Fig. 6).

In west fault slope break zone, it is mainly the Paleogene lithologic trap of glutenite and turbidite fan. There are also some traps of fault block and fault nose. They are all close to the oil sources and form the favorable oil gas gathering belt in this area.

In middle strike-slip fault tectonic zone, the main structural styles are Neogene fault block and fault nose, Paleogene buried hill anticline traps in stratigraphic overlap tectonic belt. Those tectonic styles are analogous to the Shengli seabeach style and the favorable oil gas gathering belt in this area.

The tectonic characters in east stratigraphic overlap tectonic belt are drape anticline structure over buried hills with slope zone and structure of stratigraphic overlap. The former based on large drape anticline traps with stratum, lithology, fault block (nose) traps can form large-scale composite hydrocarbon accumulation zone. This zone has the same setting and reservoir forming conditions of Jiyang rag and Chengdong arch, which is a material base of large-scale oilfield. In addition, the Tertiary system overlapped on buried hill that formed extensive stratigraphic unconformity trap; if they matched the low-amplitude fault nose, it can also form stratum, lithology, fault block traps. The well oil-bearing reservoir of this kind of traps has been proved by Shenghai well 8 and 2(old) in Chengdao eastern slope zone Jiyang rag with character of multilayer and superimposed distribution. This oil reservoir also has the feature of high-producing partially. The raised up area in Paleogene and substratum.

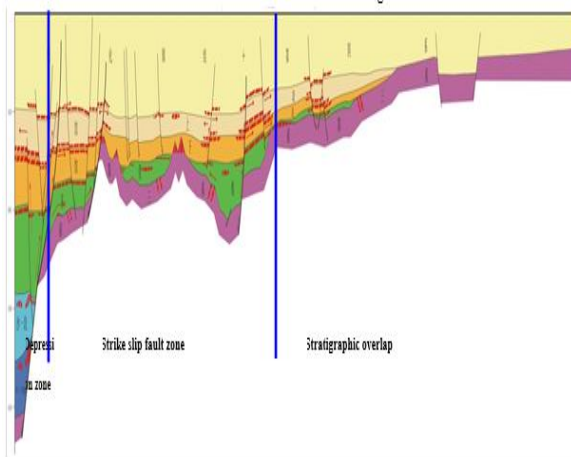


Figure 6: NE trending oil reservoir section in Eastern Liaodong exploration region

7. Accumulation Model

Based on the discussions and the results from drilling and observation, there are several styles of pool, such as lithology-tectonic reservoir, formation overlap reservoir, lithology reservoir and denudation stratigraphic unconformity reservoir in Eastern Liaodong exploration region of Shengli Oilfield (Fig.5).

Lithology-tectonic reservoir: This kind of reservoir has been found in Shengshun well 1 and 100. The fullness degree of lithologic trap is relatively high (>80%). In Shengshun 1 of Dongying formation, the trap amplitude is 120m, the reservoir height is 100m, and oil-bearing interval in structural high part is 82m in length and 24m in depth of stratum. The lower part of the oil layer gradually thinned to 4.2m (oil-water layer); In lower Guantao formation, the trap amplitude is 60m, the reservoir height is 45m, and oil-bearing interval in structural high part is 129m in length and 43.2m in depth of stratum. The lower part of the oil layer gradually thin (44.9m/4layers of oil-water layer).

Formation overlap reservoir: There are several large unconformity surfaces in Eastern Liaodong exploration region because of the effect of multiple episodes tectonic movements. The formation overlap reservoir is formed as the Paleogene and Neogene stratum overlaps on the Pre-Tertiary layer

respectively along the slope. This kind of reservoir has been found in the bottom of Shengshun well 100 Dongying formation. There are two oil and water zones of some 11 meters in thickness in Dongying Formation, near Shahejie formation and Kongdian formation. The height of oil column of reservoir is less than 50m.

Lithology reservoir: There are large suite of glutenite in up Guantao and Minghuazheng Formation, Eastern Liaodong exploration region, and the ratio of reservoir between strata can reach 67%. Because of the neotectonics movement, this glutenite of fluvial facies could either be the horizontal transporting layer; or form the traps to oil accumulation under the control of shielding layer. Both the gas layer and oil gas drilled by Shengshun wells 1 and 2 in in Minghuazheng Formation are lithology reservoirs.

Unconformity stratigraphic erosional reservoir: There are multi-stages regional unconformity plains, such as: plane between the Tertiary and Pre-Tertiary, between the 4th Shahejie –Kongdian group and Dongying Formation, between the Dongying and Guantao Formation. The viscous oil patches in Shengshun wells 1 and 100 of the 4th Shahejie –Kongdian group show the unconformity plains could either be the horizontal transporting layer, or form the traps to oil accumulation under the control of shielding layer.

From the quantity of resource table (Table 4), the mainly and most important reservoirs in Eastern Liaodong exploration region(Guantao, Dongying formation) are stratigraphic overlap oil reservoirs, whose total oil-bearing area is 34km², reservoirs is 36m in thickness, quantity of resource can be 8320×10⁴t. There are other kinds of reservoirs such as structural oil reservoir whose total oil-bearing area is 10 km², reservoirs is 36m in thickness, quantity of resource can be 2800×10⁴t; lithology reservoir is another important reservoir whose total oil-bearing area is 25 km², reservoirs is 36m in thickness, quantity of resource can be 5680×10⁴ t. In general, the prospective oil and natural gas resources of the stratigraphic overlap oil reservoirs and lithology reservoir are good and offer directions for further exploration and development in this area.

Table 4: Amount of oil resources in Eastern Liaodong exploration region

Horizon	Type	Oil-bearing area(km ²)	Thickness(m)	Unit reserve	Trap reserve (×10 ⁴ t)
Guantao Formation	Overlap	12	20	20	4800
	Structure	5	20	20	2000
	Lithology	7	20	20	2800
	Total	24	20	20	9600
Dongying Formation	Overlap	22	16	10	3520
	Structure	5	16	10	800
	Lithology	18	16	10	2880
	Total	45	16	10	7200
Total		69			16800

8. Conclusions

- (1) The hydrocarbon source rock here has some characteristics of multiple reservoir layers, large thickness, and wide distribution. Beside some Paleogene layers like Kongdian Formation, Shahejie Formation, the hydrocarbon source in this region has one more mature hydrocarbon source rocks in Dongying Formation than onshore area. Those rocks with abundant organic matters are buried in more than 2.5 km depth, which is the material base of large-scale oilfield.
- (2) There are multiple reservoir-seal assemblages, the reservoir-seal assemblages in lower Guantao group and Dongying group are the best reservoir-seal assemblages in the exploration region.
- (3) There are sandstone passage systems, fault transportation systems and unconformity transportation systems in study region. As different tectonic belt and positions, the transportation systems have different features, they all of them constitute one multiple transportation systems.
- (4) There are many kinds of traps in the study region. Different trap types and trap assemblages in different tectonic belts, that formed the complex trap zone.
- (5) Comprehensive analysis show that there are mainly 4 kinds of reservoir, such as lithology-tectonic reservoir, formation overlap reservoir, lithology reservoir and denudation stratigraphic unconformity reservoir in Eastern Liaodong exploration region of Shengli Oilfield.

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The author confirms that this article content has no conflict of interest.

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